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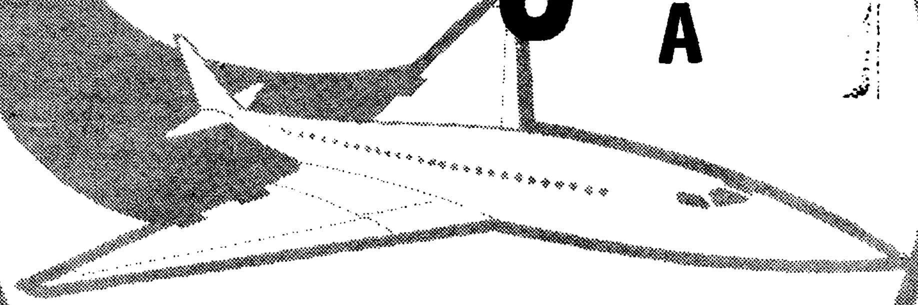
Airborne Data Link Operational Evaluation Test Plan



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16. Abstract

This plan desc... s an end-to-end study of operational concepts and procedures associated with the introduction of electronic data communications between flight crews and air traffic controllers. Full performance controllers from terminal facilities will interact with type-related line pilots in four cockpit simulators networked into the Federal Aviation Administration Technical Center's Air Traffic Control Laboratory.

Measures of human performance will gain insight into flight crew alerting, display placement, and the utility of voice annunciation of Data Link Messages. Direct measures of workload, communications efficiency, Data Link attention time (measured by head position), and aircraft state will be gathered and translated into recommendations for the cockpit display configuration.

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EXECUTIVE SUMMARY

This plan describes the conduct of a study of Data Link operational conditions and human factors for the terminal airspace around the Raleigh-Durham North Carolina area.

Four remote cockpit simulators (three B-727 and one B-737) were networked into the Federal Aviation Administration (FAA) Technical Center's Air Traffic Control (ATC), Automated Radar Tracking System (ARTS IIIA) laboratory to form the end-to-end testbed for the study.

Full-performance level air traffic controllers and type-rated airline pilots will participate as subjects. The controllers will be selected from the Air Traffic Data Link Validation Team (ATDLVT) and the pilots will be obtained from the Airline Pilots Association (ALPA), Air Transport Association (ATA), and the Radio Technical Commission for Aeronautics (RTCA).

Research questions posed for this study include: (1) What is the minimum crew alerting required, i.e., is aural alerting alone sufficient or is visual and aural alerting required?; (2) Is control display unit (CDU) location (forward vs. aft of the throttles) a factor?; and (3) Will voice annunciation of Data Link messages improve pilot response time and lessen pilot head-down time? Data collection includes CDU level of effort (keystrokes and errors), response times, workload, video taping of pilot head position (Data Link attention time), subjective data through questionnaires, and aircraft state and position data.

1. INTRODUCTION.

1.1 OVERVIEW.

This study is the first in a series of evaluations of Data Link products and services where pilots and controllers participate in simulations of aviation operations. The approach represented in this test plan constitutes a flight deck experiment to be performed in preparation for an end-to-end Data Link simulation planned for late 1993 or early 1994.

Establishment of guidelines for cockpit implementation of Data Link computer-human interfaces (CHI) is the focus of this evaluation. To this end, this experiment will focus on a number of cockpit Data Link human factors issues that have been identified as important by the Airline Transport Association (ATA) and other bodies.

1.2 PURPOSE.

This evaluation will examine crew alerting methods, display location, and presentation of Data Link messages. Recommendations will be made regarding the acceptability of implementation options relative to operations in terminal airspace. Findings will be generalizable to the air traffic control (ATC) systems and aircraft types used in the study.

1.3 SCOPE.

The cockpit Data Link CHI study will assess a selected set of Data Link services (see appendix A). Air traffic controllers will interact with radar displays driven by Automated Radar Terminal System (ARTS) IIIA equipment. A thorough description of the ARTS IIIA implementation is contained in [1]. Pilots will interact with control display units (CDUs) in cockpit simulators.

Flight deck data collection will be limited to four analog display aircraft including one B-737 and three B-727 cockpit simulators. Automated entry of data clearances into flight controls will not be part of the test design.

The rationale for using analog instrument cockpits is the flexibility offered in installing and interfacing display devices and crew alerting schemes. Moreover, the analog phase II cockpit simulators available for research purposes can incorporate Data Link without risking decertification. A further constraint on this study is the requirement for reasonable maturity in the cockpit configuration. Federal Aviation Administration (FAA) researchers felt that, for this particular evaluation, the simpler CDU configuration is better understood and more easily controlled than a flight management computer (FMC) configuration with coupled flight control.

Emergency conditions such as engine fire will not be incorporated in the scenarios, nor will traffic be placed on the runway resulting in

go-around maneuvers. Potentially catastrophic events such as these are beyond the scope of the evaluation because available Data Link services have not been defined to accommodate them. Also, Data Link in the terminal area has not yet been demonstrated to be appropriate for other than routine communications.

1.4 RESEARCH QUESTIONS.

The ATA Information Transfer Subcommittee has published a requirements paper [2]. Research questions addressed in this test plan are derived, in part, from [2].

Reference to [2], section 5.5.3, "Distinction of Alerts," leads to the first research question: What kind of alerting scheme is required to distinguish alerts for Data Link messages from other cockpit alerts? The FAA's Aircraft Certification Office has been preparing requirements for domestic cockpit Data Link systems and is considering the need for light and sound annunciation of Data Link messages. FAA flight test pilots expect that some combination of an indicator light and alerting sound may be needed to provide a unique Data Link alert. This could be a nondistinctive sound with a distinctive light (or message common to other such alerts) or a non-distinctive light or message with a distinctive sound.

It was decided to test the former situation in this study because the analog instrument cockpits involved already have a non-distinctive message sound known as the selective calling signal (SELCAL). A major airframe manufacturer is also apparently considering the use of a general purpose communication annunciating sound in future cockpits. The addition of a distinctive light will provide a unique Data Link alerting scheme. Therefore, the research question of interest is whether there is a difference in pilot communication behavior (response time to a Data Link message) between the conditions of non-distinctive (SELCAL sound only) versus distinctive (SELCAL sound plus "ATC" light) alerts.

Given the low frequency of SELCAL alerts for company or cabin calls in terminal airspace, a SELCAL sound will be associated with a Data Link message most of the time. Therefore, there may not be much difference in pilot response time between the planned two alerting conditions unless the light (which stays on until the message is accessed) works as a reminder during periods of high cockpit workload.

However, this study is part of a series of Data Link experiments that will expand to encompass oceanic and en route airspace. It will be useful to use the same alerting scheme in other environments to contrast the results with crew behavior in terminal airspace. Such work will help determine what type of alert is adequate for Data Link annunciation in all phases of flight. For example, the data from these studies may show that a general purpose auditory alert (such as SELCAL) results in acceptable pilot response times in terminal, but not in en route airspace, given that more company and cabin calls are experienced in the latter situation. Further

research is planned to evaluate other alerting schemes, such as digitized voice.

The second research question posed for this evaluation is: What is the acceptability of an aft-center pedestal mounted CDU given head-up requirements of terminal operations? This issue is of interest because of the need to consider aft-CDU locations in order to retrofit some cockpits with Data Link. Although there is no item in [2] regarding display placement, this issue relates to section 3.2, "Flight Crew Response Time" and section 5.2.5, "Head Down Time."

The third research question addresses presentation of incoming voice messages (section 5.2.7 in [2]). There is interest in whether digitized voice annunciation of incoming Data Link messages will improve pilot response time and result in reduced head-down time. The study will compare three message presentation formats: voice radio, Data Link, text format, and Data Link text format plus digitized speech.

2. EXPERIMENTAL APPARATUS.

2.1 ATC SIMULATOR.

The ARTS IIIA laboratory at the FAA Technical Center will be used to provide ATC for this study. The ARTS is a facility which uses actual National Airspace System equipment to create a system capable of realistically exercising Data Link applications. The ARTS Enhanced Target Generator (ETG) allows the system to act as a functioning ATC simulator by providing radar data and voice radio inputs from simulation "pilots" operating from terminals in the laboratory.

The ARTS laboratory is connected to a VAX 11/750 computer which acts as an emulation of the future ground Data Link processor. The VAX computer supports digital communication between simulation pilots and controllers. It provides two-way communication between controllers and high-fidelity aircraft simulators or actual airborne systems using Mode S or any other installed Data Link technology. The VAX computer also carries navigation data from the remote simulators to the ARTS in order to permit the display of aircraft targets on each radar screen. At this time, Data Link signal formats are not Radio Technical Committee for Aeronautics (RTCA) SC-169 data dictionary compliant. Future studies will be compliant.

2.2 COCKPIT CONFIGURATIONS.

Analog cockpit aircraft will be employed in this evaluation. The aircraft types represent transport category aircraft. Cockpit descriptions are contained in the following paragraphs.

Two B-727-200 cockpits, one B-727-100, and one B-737-300 cockpit are networked into the testbed. Two of the four cockpits will be equipped with annunciation lamps mounted under the glare shield, one

prominent in the field of view of the left seat and one prominent in the field of view of the right seat.

Each cockpit will have a CDU mounted in the center pedestal. Two cockpits will have CDUs mounted forward of the throttles and two cockpits will have CDUs placed behind the throttle quadrants. Auditory alerting and speech production will be provided by personal computer (PC) generated sounds played over a loudspeaker. All four analog cockpits are classified as Phase II flight simulators [3].

2.3 DISPLAYS.

2.3.1 Multifunction CDU.

This display is very similar in form, fit and function to displays commonly used as FMC CDUs. It is a Honeywell model CD-800 which measures 6.8 inches high by 5.7 inches wide and fits in standard Dzeus rail mounting. The display surface is 3.8 inches by 3.8 inches and can display 9 lines by 24 columns of text in 2 fonts. A message recall switch is mounted on the front bezel in the function key cluster. Brightness is continuously adjustable from full brightness to a minimum, but still viewable, level. Background illumination is controlled by the aircraft master dimmer circuit.

2.3.1.1 Display Formats.

Each uplink, except initial contact, requires a wilco or unable response to complete the transaction. These responses are directly selectable by the line select keys adjacent to the Cathode Ray Tube (CRT). Messages in the message log are stored from most recent to oldest and are selectable using the line select keys [10,12]. Messages are marked to indicate type origin and pilot response associated with each message. All functions are selectable from a top level menu. If a new Data Link message is received while the user is reviewing logged messages, a bezel mounted annunciator light will activate and the new message can be accessed using the "DIR" key, as usual. See appendix B for a description of the Honeywell CDU and its operation.

2.4 CREW ALERTING.

2.4.1 Auditory Alerting.

Auditory alerting will be provided by a "Pro Audio Spectrum 16" brand audio digitizer card installed in the Data Link message processor. This card can record audio and play it back under process control. It is capable of 16 bit record and playback at a rate of 2 kilohertz (kHz) to 44.1 kHz. Sounds will be heard in each cockpit through a self-powered SONY SRS-88 loudspeaker with user-controlled volume.

A SELCAL sound will be recorded and played back as part of the alerting experimental factor. The SELCAL sound used in B-727 cockpits is usually a two-tone, mechanical doorbell chime. The same

units are available for domestic use. The SELCAL sound used for this experiment was digitally recorded from a "Nutone" brand doorbell.

2.4.2 Visual Alerting.

Visual cues will be provided by a combination of glare shield mounted, blue lens, aviation-type lamps and lighted distinctive message indicators on the CDUs or CDU lamps alone (depending upon experimental condition) [11,13]. All visual cues will be lit as long as the current Data Link message is pending. Glare shield lamps will not flash.

It is recognized that, in the experimental conditions with forward mounted displays and no glare shield light, pilots may detect the small "DSPLY" light (which should be visible in their peripheral visual fields) on the CDU upon hearing the SELCAL sound. As a result, the factors of display location and alerting may interact. However, the presence or absence of this interaction will provide useful information on alerting. It may be the case, for example, that the CDU light will provide as good visual alerting (with respect to response times) as the glare shield light.

The ARTS IIIA Data Link software allows for only one message transmission at a time. Pilots must wilco or unable each ATC message before another can be transmitted. Therefore, during routine operations, it will not be necessary to access the message log function of the CDU to read pending messages, nor will it be necessary to maintain visual alerting until all messages are read.

2.5 SPEECH SYNTHESIS.

Announcement of Data Link messages will be provided by the same audio digitizer card and loudspeaker used for the Data Link alerting sound. A set of spoken Data Link message components have been recorded by an air traffic controller and digitized on the hard disk of each remote simulator Data Link PC. These recordings will be accessed by control software when Data Link messages are received from ATC. As with a text message, a Data Link alert will be activated and the pilot will be required to press a key on the Data Link CDU to hear the message. The message will simultaneously appear in text format on the CDU. In both text only and speech with text conditions, a wilco or unable response must then be selected from the Data Link CDU.

3. SUBJECTS.

All subject pilots will be type-rated in the aircraft that they will operate. All first officers will be qualified (but not necessarily type-rated) in the specific aircraft. Subjects may or may not be current in the aircraft. A captain and first officer (as opposed to two captains) will fly in each crew. In the rare event that there is a last minute cancellation, a retired pilot (type-rated captain or qualified first officer) with recent flight simulator experience,

may be substituted. It is planned to obtain captains and first officers from the Airline Pilots Association (ALPA). Participation from ATA and RTCA will also be invited.

Given a survey of available subject pools, it will not often be possible to recruit flight crews from the same airline. A policy of mixing crews from different airlines will place all crews under the same starting conditions. Intentionally mixing crews from different airlines will eliminate the problem of crews from different airlines not being familiar with each other's procedures. This will require crews to agree upon basic flight procedures during the pre-experiment briefing.

The briefing will cover a description of the experiment, use of cockpit checklists, airspace information, mission description, and Data Link procedures. Each crew will have the requirement of one day at a flight simulator location. A total of 32 crews will be needed for the study.

4. EXPERIMENTAL DESIGN.

4.1 EXPERIMENTAL FACTORS DESCRIPTION.

From section 1.4, there are three equipment-related independent variables that can be examined in a controlled experiment. These include crew alerting, display location, and message display.

4.1.1 Crew Alerting.

Coincident with the arrival of Data Link messages, flight crew attention will be directed to the Data Link CHI by one of two alerts. Crew alerting will consist of either SELCAL sound only or SELCAL tone combined with forward primary field of view visual alerting (a blue light mounted on the glare shield in front of each pilot). In both cases, a light on the CDU will activate at the same time as the other alerts. Visual alerting will be maintained as long as a Data Link message is pending. There are two levels in this factor (SELCAL sound only or SELCAL sound with glare shield light).

During the study, in order to reinforce to subjects that SELCAL is a multipurpose cockpit annunciation sound, it will be triggered for other messages during some of the flights. During 44 percent of the flights, the SELCAL sound will be activated. The crew will have been previously instructed that they should ask the site facilitator (who is also in the cockpit) for a preprinted company message. The message will instruct them regarding a gate change.

4.1.2 CDU Location.

Display location is derived from a study that surveyed anticipated Data Link display locations in airline aircraft [4, 5]. The two most common locations were center pedestal forward and aft of the throttle quadrant. There are therefore two levels in this variable.

CDUs will be mounted in aft positions in simulators one and two and in forward positions in simulators three and four.

4.1.3 Message Display.

Three experimental conditions will be created that relate to the method for displaying ATC instructions. In one, the arrival of incoming Data Link messages will be simultaneously announced by some combination of visual and auditory alerts. After pressing the DIR key on the CDU bezel, the Data Link message will be displayed in text format. Wilco or unable is then selected, using other CDU keys.

In the second condition, the button press on the CDU will activate a digitized air traffic controller's voice that speaks the message over a cockpit loudspeaker. Simultaneously, the Data Link message text will be displayed on the CDU. The aircrew will be able to replay the voice message by pressing a key on the CDU. The wilco or unable response will be made using CDU keys.

The third communication condition will be voice only (Very High Frequency (VHF) radio). All ATC instructions will be transmitted over the radio channel with no other visual or auditory alerting. This situation is included so that baseline data can be collected on pilot situation awareness, communication activities, and workload. Accordingly, a proportion of the flights conducted by each flight simulator will be with voice only communication (the CDUs will be turned off) and the rest will involve Data Link usage.

4.2 TEST DESIGN.

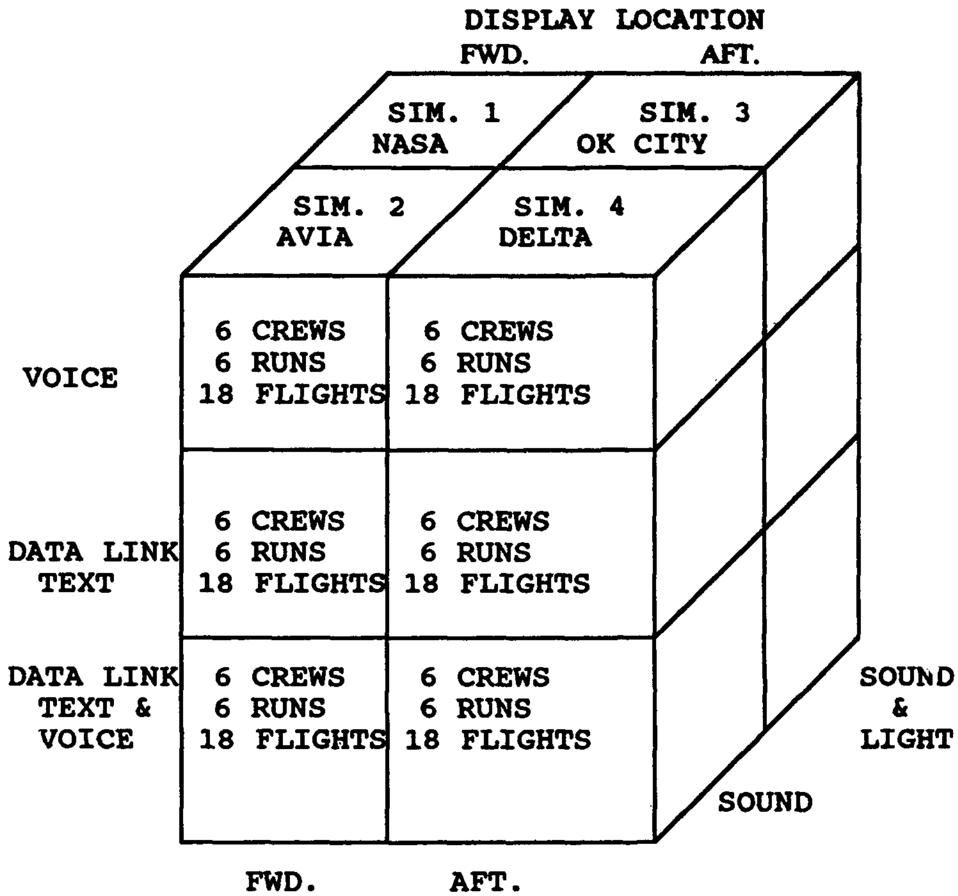
The message display factor has three levels, and the alerting and display location factors each have two levels, resulting in a 3x2x2 mixed plot, factorial experimental design. Figure 1 shows the four simulator configurations for alerting, location, and message display. The CDU location and alerting variables are between-subjects factors, while the message display factor is within-subjects.

It should be noted that, although voice-only is listed as one of the levels of the message display factor, it is only included in order to collect baseline data on a number of the dependent measures. The between-subjects factors of display location and alerting will not be relevant in voice-only conditions. The remaining paragraphs in this section describe the dependent measures and data collection methods.

4.3 NUMBER OF RUNS.

It is planned to conduct the experimental trials over the course of 8 days for 8 hours per day (including pilot training and debriefing). Prior to the first experimental run, a 20 minute Data Link practice flight will be completed without the simulators being

on-line with the FAA Technical Center systems. Following this will be three data collection runs. Each will last 1 1/2 hours, thus allowing for 3 runs per day (with breaks). The order of the runs will be counterbalanced to compensate for practice effects.



NOTE: The message display factor is carried across all simulators. The combinations of other factors are unique to each simulator. A minimum set of six runs is needed per simulator site for a full set of data.

FIGURE 1. EXPERIMENTAL DESIGN.

This will result in a total of 24 runs available for data collection for simulator site. Pilots will fly a minimum of three flights per run (three arrivals) and will alternate roles of flying pilot (FP) and non-flying pilot (NFP) between each flight. This will create a total of at least 72 flights over the 8 days. There will be a minimum of 24 arrival flights in each cell of the design. However, only six crews at each site will be necessary to collect an acceptable set of data. The other 2 days of data collection will be included to compensate for lost runs due to scheduling limitations at one simulator site and to act as backup should technical problems result in loss of data.

4.4 DEPENDENT MEASURES.

The dependent variables in this evaluation are:

a. Communication activity.

b. Errors.

c. Time intervals from message annunciation to pilot reaction.

d. Situation awareness (SA).

e. Workload.

f. Pilot head-down time. (Data Link attention time.)

g. Fuel burn.

h. Crew interactions.

i. Subjective opinions regarding the cockpit Data Link interface, alerting methods, display location, and speech synthesis.

j. Time Coordination.

A description of the dependent variables and methods to measure them are presented in the following paragraphs.

4.4.1 Communication Activity.

Communication effort will be compared between voice and Data Link by measuring the total amount of time pilots spend using the VHF radio and Data Link modalities. Level of effort for Data Link (between the Data Link related experimental conditions) will be gauged by the number of keystrokes used to access and respond to Data Link messages.

Each time a CDU keyboard button is depressed, its associated ASCII code will be logged, and time tagged with 0.1 second precision. Each simulator location will employ a PC processor functioning as display driver, telephone circuit interface, data logger, and audio generator. This processor will collect cockpit event data, time tag each event, and store the data onto hard disk storage media. A video camera in each cockpit will also record Data Link activity. At the end of each day, the site coordinator will copy all data files onto floppy disks for overnight mailing to the FAA Technical Center. A second set of floppy disk file copies will be made and retained at the site for backup.

The database formed by keystroke data will be organized by run and will be correlated post-facto with records from computers at the FAA Technical Center. Controller and pilot microphone use will be recorded at the FAA's laboratory voice switching system through the active push-to-talk status word in the simulator data stream. Each

message will be time stamped to one second precision. Voice recordings of all controller and pilot interactions will also be available from the laboratory voice switching system.

4.4.2 Communication Errors.

The site facilitator will note the incidence of voice and Data Link errors by recording the number of times during each flight that pilots or controllers initiate a voice radio transmission aimed to clarify or correct a previous message.

4.4.3 Time Intervals.

Response time epochs will be logged based on key events in the Data Link transaction. These are defined as follows and are shown in figure 2. Each event will be recorded by the appropriate FAA Technical Center or remote simulator site computer.

```
              1              2               3               4
            Crew         Access DL        Wilco/         Simulator
            Alert         Message         Unable         Response
              |              |               |               |
 Cockpit      ↓    epoch 1   ↓    epoch 2    ↓    epoch 3    ↓
 Events    /////////////////////////////////////////////////////
 DL - DATA LINK
```

NOTE: KEY COCKPIT AND ATC UPLINK AND DOWNLINK EVENTS AND TIME EPOCHS TO BE MEASURED.

FIGURE 2. KEY RESPONSE TIME EVENTS

event 1: Incidence of crew alert announcing message pending.
event 2: Pilot presses message key to call message to viewing surface.
event 3: Pilot presses wilco/unable key.
event 4: Pilot makes control input and the simulator responds to uplink message.

The time measurement epochs associated with each interval are:

epoch 1: Begins with incidence of crew Data Link alert. Ends with pilot selecting the message for display.
epoch 2: Begins with pilot selection of the message for display and ends with the selection of a wilco or unable response.
epoch 3: Begins with a pilot wilco or unable selection and ends with a control input as indicated by navigation data transmitted by the simulator. Navigation data will be available from the ARTS system.

4.4.4 Situation Awareness (SA).

There is concern by the ATA that aircrew SA will be degraded by the removal of the radio "party line" as ATC communication shifts to Data Link. In order to evaluate this concern empirically, aircrew SA will be measured during both voice-only and Data Link runs. There are a number of different kinds of party line information (PLI) gained from radio communication between ATC and aircraft and between aircraft. Midkiff and Hansman conducted questionnaire research on important PLI elements [6]. The items relating to terminal area and final approach are listed in table 1. Each SA component has been evaluated to establish its source and whether each item potentially will be effected by the Data Link environment set for this experiment.

As can be seen in table 1, a number of tower-related SA items will not be relevant in this study in that there is no tower ATC

TABLE 1. SITUATION AWARENESS ITEMS AND SOURCES FOR EACH ITEM.

SITUATION AWARENESS ITEM	SOURCE	AFFECTED?
NEXT COMM. FREQUENCY	ARRIVAL/FINAL ATC	YES
WEATHER SITUATION	ATIS	NO
WEATHER SITUATION	AIRCRAFT	YES
TRAFFIC SITUATION	ARRIVAL/FINAL ATC	YES
SEQUENCING	ARRIVAL/FINAL ATC	YES
HOLD SITUATION	ARRIVAL/FINAL ATC	NO
TERMINAL ROUTING	ARRIVAL/FINAL ATC	YES
APPROACH CLEARANCE	ARRIVAL ATC	YES
CONTROLLER ERRORS	ARRIVAL/FINAL ATC	YES
MISSED APPROACH	TOWER ATC	NO
WINDSHEAR	AIRCRAFT	NO
GO AROUND	AIRCRAFT/TOWER ATC	NO
AIRCRAFT ON RUNWAY	AIRCRAFT/TOWER ATC	NO
BRAKING ACTION	AIRCRAFT/TOWER ATC	NO
TAXIWAY TURNOFF	TOWER ATC	NO

position. The items that will be handled by the ARTS IIIA Data Link message sets relate exclusively to ATC instructions for altitude, course, or speed changes and runway clearances. Use of the Data Link medium for these messages may influence the traffic SA of pilots. Other SA information, such as weather, will continue to be communicated using voice.

Thus, in a flight scenario where Data Link is the only medium for transmitting navigational instructions, pilot SA effects will be limited to a probable reduction in their understanding of the positions, movements, and plans of other aircraft relative to their own. Consequently, this study will focus on what will be called "traffic SA." However, there may be indirect effects of Data Link use on weather awareness as well. If a pilot is not informed as to the relative positions of aircraft ahead, VHF communications by these aircraft about inclement weather conditions may be heard, but not comprehended as relevant.

Endsley has defined three levels of SA [7]. Level 1 involves the perception of situational elements or the important facts in the environment. In Level 2, "Information Integration," the operator determines the meaning of this information and then is able to generate Level 3 SA, "Projection of Future Status and Actions of Situational Elements." In this experiment, SA will be assessed by asking about surrounding aircraft, by observing pilot responses to a scripted weather problem, and by assessing attitudinal factors.

Level 1 SA (environment perception), will be probed using two methods of traffic awareness . The first will only be used for downwind approaches, given the limited flight time in straight-in arrivals. About ten minutes after injection into the problem (before cockpit workload has reached a peak), the NFP will be asked to mark the location and altitude of nearby traffic on a simple map. For all approaches, as soon as a simulator has transferred communication to the final sector frequency, three brief questions will be asked of the aircrew. In order to sample shared SA, either pilot will be allowed to answer. The questions are:

a. What aircraft is immediately ahead of you?
b. Name another aircraft at your altitude.
c. How far outside the marker is ATC going to turn you into final?

In order to compare pilot reports against the real ATC situation, a video camera will tape each scenario at an unoccupied workstation in the ARTS IIIA lab. This will be sufficient to collect aircraft data in the final sectors. SA map comparison data will be available from ARTS IIIA computer files.

The SA maps and probe questions will be initiated by the site coordinator. Responses will be noted along with computer clock time. The coordinator will be permitted to use discretion to skip an SA measurement event if the flight crew is too busy, if the

content of the probe is inappropriate given the aircraft's phase of flight, or for other reasons.

Level two SA measure will be problem-related and will be measured during one flight each run. While in the arrival sector, (shortly after the map data has been collected) the ARTS IIIA ETG-generated aircraft ahead of a flight simulator will use voice to report turbulence and request a different altitude. The site facilitator will note whether the flight crew discussed the weather situation and if a change in altitude or heading was requested.

Level three SA measure will focus on pilot attitudes. After each run, the site facilitator will ask the pilots to complete a short questionnaire. Items will include quality of communication, pilot confidence, amount of information available, planning capabilities, safety assessment, and comments.

4.4.5 Subjective Workload.

The use of cockpit Data Link may affect pilot workload and workload may vary given different alerting, display location, and message presentation (text versus voice) conditions. Workload will be measured using a unidimensional instrument, the Modified Cooper-Harper Scale [8]. After each flight, the site facilitator will ask each member of the flight crew to note their peak workload level during the prior flight on a single, ten-step scale.

4.4.6 Head-Down Time.

Accessing, reading, and responding to Data Link messages may increase head-down time. In order to assess this, a video camera will be positioned behind the pilots along the centerline of each cockpit. It will be aimed to show the backs of the pilots heads, the glare shield Data Link annunciator lights, and the Data Link CDU. During each flight, a video record will be made of pilot head movements. As each Data Link message is received (as marked by the activation of the SELCAL sound), the time each pilot spends looking at the Data Link CDU will be measured. While this will not provide data on head-down time for reasons other than Data Link, it will allow an assessment of the amount of visual attention the Data Link system commands.

4.4.7 Fuel Burn.

Each simulator site has the capability to measure fuel used. Fuel burn will be measured from the time of release from the insertion point until touchdown. This will be recorded by the site coordinator after each flight.

4.4.8 Crew Interactions.

During each flight, crew discussions regarding Data Link will be recorded, using the audio input of the cockpit video camera. In addition, inflight observers will annotate pilot comments and reactions.

4.4.9 Subjective Opinions.

At the end of each run, pilots will be asked to respond to questions regarding the usability of the Data Link interface. At the end of each day, the pilot will be encouraged to offer feedback regarding cockpit Data Link implementation.

4.4.10 Time Coordination.

All computers involved in the simulation will receive regular time codes from the FAA Technical Center's Motorola computer to ensure comparability of data records. A computer time clock will be displayed in each cockpit for the site coordinator.

4.5 ATC MESSAGES.

The ATC message set consists of the following Data Link messages: transfer of control (TOC), menu text (MT), and terminal information (TI). These are more completely described in appendix A. A randomly selected simulated equipment delay time of zero to four seconds will be used with the Data Link messages. There will be no simulated Data Link communication failures injected, and pilot wilco responses will be timed out after 40 seconds at the ARTS display. In the voice-only runs, ATC instructions will consist of typical voice transactions for the terminal area.

4.6 FLIGHT SCENARIOS.

One basic flight scenario will be written for the experiment and each aircrew will experience it three times (twice in the Data Link conditions and one in the voice condition). Aircraft identifiers will be varied between runs to reduce the chance that pilots will be able to remember aircraft around them. Aircraft targets will be generated by the ARTS IIIA ETG system and by the four remote flight simulators. Scenarios will be designed to operate with an instantaneous traffic load of approximately five to eight aircraft in each of the two sectors (arrival and final) per side of the airspace (east and west).

Runs will last 1 1/2 hours each with 3 arrival flights per run. Aircraft will be 100 percent voice (no Data Link) in the voice-only communication condition and a mixture of 80 percent Data Link and 20 percent voice equipped in the Data Link communication conditions. Flight simulators will always be Data Link equipped in Data Link runs. Data Link aircraft will be permitted to use voice communication during Data Link runs. This will result in decrease,

but not elimination of the frequency of voice messages in the Data Link condition.

The rationale for a mixture of Data Link and voice-only aircraft and allowing controllers to use voice in Data Link conditions is that it is more like the anticipated real-world situation. There will continue to be (for the foreseeable future) non-Data Link aircraft and controllers will not be restricted to using Data Link only. Under these conditions, there will still be a drastic reduction in voice radio traffic in the Data Link experimental conditions. It will be interesting to determine whether the rare voice-only aircraft in Data Link runs will be more likely to enter the SA of simulator pilots flying in Data Link-equipped aircraft.

Flights will be conducted in the Raleigh-Durham terminal airspace. Conditions will be instrument flight rules (IFR) with 1000 foot ceiling and 3 miles visibility. (See appendixes C and D for complete descriptions of the airspace and mission.) Flight simulators and computer-generated ETG aircraft will fly downwind or straight-in approaches to both runways. No departures will be flown. Flight simulators will be assigned to one type of approach and will alternate runways. This will result in a complete set of data for all approach types for any given between- or within-subjects comparison.

Crews will be asked to hand-fly all approaches. While this is not necessarily normal procedure, it will require more effort than using the autopilot. Data Link communication can then be assessed in a worst case (for normal flight conditions) rather than low cockpit workload environment. Crews will fly until the aircraft has touched down at which point the simulator will be reset to the next starting point.

4.7 SUPPORT PERSONNEL.

In the ARTS IIIA laboratory, four air traffic controllers from the Air Traffic Data Link Verification team (ATDLVT) have been recruited to act as controllers. Local pilots will be trained in the operation of the ARTS IIIA ETG pilot terminal and will act as pseudo-pilots. Additional personnel will be needed in the ARTS IIIA lab to act as Data Link terminal operators. These individuals will be FAA or CTA staff. See appendix E for a diagram of the ARTS IIIA laboratory workstation layout.

A site coordinator will be stationed at each remote simulator location. It will also be the coordinator's responsibility to ensure that the subject pilots arrive on time and at the proper location. The coordinator (who is also a pilot) will greet visiting pilots and provide an orientation briefing and training session. The coordinator will ride "jump seat" during the missions to gather data, as required. This person will also serve to answer any pilot subject questions once the mission has begun. A local technician or other assistant will handle communication with the FAA Technical

Center and other tasks required to conduct the simulation. See appendix F for a list of support staff.

4.7.1 Training Orientation.

Prior to the experiment, flight crews will be sent information on the airspace, scenarios, and operation of the Data Link interface. When each crew arrives at a simulator site (1 1/2 hours before the first flight), the site coordinator will provide a briefing on the goals of the experiment, airspace characteristics, operation of the Data Link cockpit interface, and cockpit procedures. Pilots will be able to exercise the Data Link communication system by invoking a selftest function. This will permit them to display and respond to a set of typical Data Link messages. Following this, an off-line Data Link simulator practice flight of 20 minutes duration will follow an approach sequence to allow crews to practice cockpit and Data Link procedures.

4.8 DATA REDUCTION AND ANALYSIS.

Data Link data from flight simulators will be contained on computer diskettes in IBM PC compatible format. The disk files will hold records of all Data Link messages, logs of all keystrokes and time events as described in section 4.4.1. In addition, the ARTS processor will provide information on simulator navigation. The laboratory voice switching system will record voice transactions. There will also be data from questionnaires and videotapes as collected by the site facilitator.

Appropriate statistical measures including analysis of variance (ANOVA) will be computed on the resulting sets of dependent measures. It will be possible to examine the effects of each independent variable (alerting, location, and message display) as well as the interactions of these variables.

5. SCHEDULE.

The daily test schedule for this experiment is found in appendix G.

5.1 SHAKEDOWN TESTING.

Prior to the experiment, 4 weeks of trial runs will take place (beginning the week of March 22, 1993). The first week will be devoted to testing the flight scenario without flight simulators. Following this (starting the week of March 29, 1993), flight simulators will be tested in groups, as available. During the final week of debugging, all four simulators will be included and simulation system functions, aircraft coordination, and data collection procedures will be tested.

On April 15, 1993, the experiment will officially start with controllers and flight crews. However, the first 2 days of data collected will be used as backup should technical problems interfere with experimental trials and to replace missing data from April 22,

1993, that will be lost due to a scheduling problem with one of the flight simulators. During the shakedown period, any areas overlooked in planning will be identified and corrected.

5.2 EXPERIMENT.

During the period April 15 and 16, April 19 through April 23, and April 26, 1993, 8 days of experimental trials will be conducted. Training of flight crews will start at 1230 EST and debriefing will occur after the last flight, with the day ending at 2030 EST. Experimental trials will begin at 1400 EST and end at 2000 EST each day.

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APPENDIX A

SERVICE DESCRIPTIONS

1. SERVICE DESCRIPTION.

There are four uplink and one downlink services defined for this evaluation. The uplinks are transfer of control (TOC), menu text (MT), terminal information (TI), and communications backup. The downlink is a service called initial contact (IC) which provides the controllers with information regarding current Automated Terminal Information Service (ATIS) and altitude clearance. Protocol definitions for link transfer syntax of each message are contained in [9].

1.1. TOC.

This service is the process whereby controllers and pilots coordinate radio frequency changes to and from en route sectors, arrival sectors, and approach sectors. The uplink information consists of the new controlling authority (sector designation or center name) and the new frequency. The current frequency will be retained on the Data Link display as old frequency. Pilot response to TOC will be the IC message (section 4.1.5, in [1]). The maximum number of characters in a TOC message is 18.

1.2 MT.

A message of this type can be an altitude, heading, or speed assignment. As a single MT message, each assignment will be a character string up to 18 characters in length. MT messages can also be linked from a combination string up to 54 characters in length. Thus a single MT message can contain from one to three assignments in any combination (except repeat clearances). The pilot response to an MT message is a wilco or unable downlink.

1.3 TI.

This service provides a text message to the pilot of up to 40 characters in length. TI messages contain information such as:

Example a: "Expect vectors to ILS approach"

Example b: "Fly present heading to intercept ILS-31R"

The pilot response to a TI message is a wilco or unable downlink.

It is interesting to note that a TI message may be combined with up to two MT messages to form a character string up to 76 characters in length. An uplink message with TI and MT combined will contain up to three elements. The pilot response to the entire message is wilco or unable.

1.4 COMMUNICATIONS BACKUP.

This service is not presently implemented in the terminal testbed.

1.5 IC.

This is a message generated by the flight crew either manually or automatically, and is sent as a response to TOC uplinks. IC contains the wilco/unable response and also contains the current ATIS (letter) designator and last assigned altitude. IC is always expected as a response to TOC in terminal airspace.

1.6 TRANSACTION DEFINITIONS.

Table A-1 shows the terminal services and associated expected replies.

TABLE A-1. EXPECTED DATA LINK TRANSACTIONS IN TERMINAL OPERATIONS.

Operation	Sequence	Uplink Message	Response
Arrival	1.	TOC to Arrival sector	IC
	2.	TI or MT or TI/MT	Wilco/unable
	N	TI or MT or TI/MT	Wilco/unable
	N+1	TOC to final approach sector	IC

APPENDIX B

HONEYWELL CDU DESCRIPTION AND OPERATION

1. HONEYWELL DATA LINK CDU.

The Airborne Data Link Study will be conducted with end-to-end simulations involving pilots flying flight simulators in multiple locations and air traffic controllers working in the FAA Technical Center, Atlantic City, NJ.

Providing Data Link communications capability in the simulator flight decks will be a Honeywell CDU specially modified for purposes of the experiment. See figure B-1 for a diagram of the Honeywell CDU.

Some of the CDU control keys have been deactivated, and others have been assigned functions not normally associated with the keys. A template specifying those special functions will be provided in each simulator flight deck for ready reference.

The Honeywell Data Link CDU has been modified to use the "DSPLY" annunciator light in the upper left hand corner of the unit to notify the pilot that a message has been received. In all simulators, additional aural or aural plus visual alerts will be provided. All other lights on the top of the CDU screen are non-functional for purposes of this study.

The pilot uses four line select keys on the left and four on the right side of the screen as action keys to select available functions. Keys below the CDU screen have the following functions:

PERF	Inactive.
NAV	Inactive.
PREV	Previous page display when appropriate.
NEXT	Next page display when appropriate.
FPL	Inactive.
PROG	Replays (voice if enabled) of currently selected message.
DIR	Displays and voices (if enabled) most recent ATC message when the "DSPLY" indicator is lit.

Of the selections displayed under ATC INDEX, all but "LOG" and "MESSAGE TO ATC" have been deactivated for this study. Selecting LOG will provide a subject and status listing, three to each page, of all messages in storage. Selecting MESSAGE TO ATC will enable composition of a message using the alpha-numeric keypad. However, this function is not enabled and will not be used during the experiment.

The sequence of events to display a Data Link message are as follows:

1. A sound or a sound plus an indicator light on the glare shield will indicate the receipt of a Data Link message.

2. The PNF will depress the DIR key on the Honeywell CDU, and the message will be displayed (and voiced if enabled).

3. The PNF will respond to the message with by pressing either the "wilco" or "unable" key on the CDU.

In the message LOG, the most recent message will be displayed first. The PREV and NEXT keys will electronically turn the LOG pages, and any desired message can be retrieved by pressing the line select key next to that message. Pilots will only be sent one Data Link message at a time. The current message must be responded to (wilco or unable) before a new message can be sent by ATC.

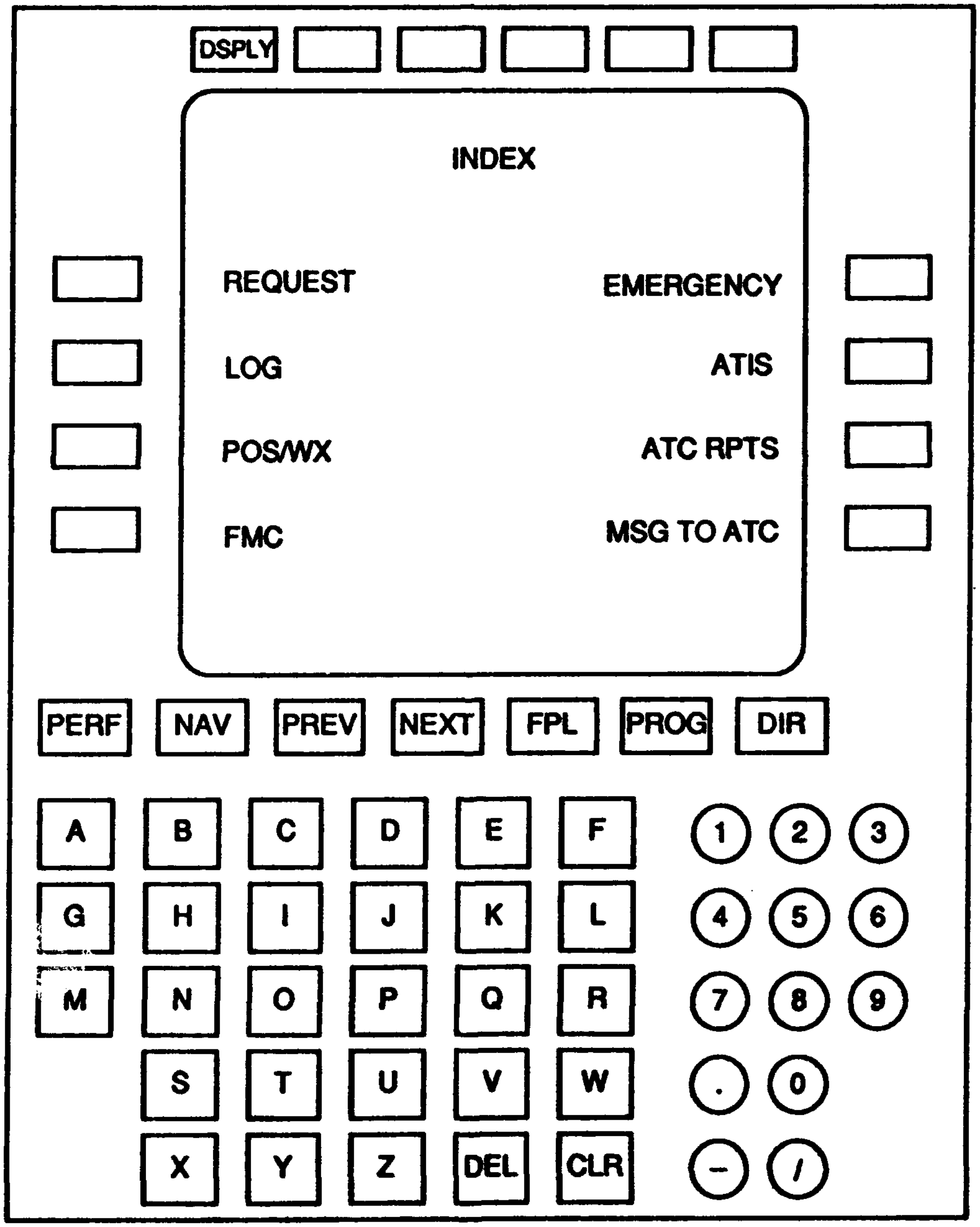

FIGURE B-1. HONEYWELL CDU.

APPENDIX C

AIRSPACE DEFINITION

1. AIRSPACE DEFINITION.

This evaluation will be conducted in a simulation of terminal airspace surrounding the Raleigh-Durham (North Carolina) airport (RDU). The airspace is marked by fix points forming an annular demarcation, roughly equidistant from the airport. Traffic which constitutes arrivals is cleared through four fixes at the perimeter of the airspace, close to the magnetic compass quadrants.

Figure C-1, excerpted from [14], shows the RDU terminal airspace, including the four fix points used as cornerposts. These are ARGAL, BRADE, BUZZY, and ALDAN. Streams of arrival aircraft are vectored onto east arrival patterns using ARGAL and BRADE intersections, and west arrival patterns using ALDAN and BUZZY intersections.

Raleigh-Durham airspace operates parallel runways oriented at 230/50 degrees magnetic heading. Both runways will be in use during the evaluation. All traffic will use runway 23 (L and R). Traffic using the west arrival patterns will use runway 23R, while the east arrivals will land on runway 23L.

Jet aircraft using the cornerpost fixes are required to cross ARGAL, BUZZY, and BRADE at 11,000 feet, and ALDAN at 10,000 feet. Non-jet aircraft are required to cross ARGAL and ALDAN at 8000 feet, and BUZZY and BRADE at 11,000 feet.

Arrival flow rate is a function of weather, number of active runways, and en route traffic loading. By the conditions stipulated in [14], the arrival flow rates range from 42 to 60 aircraft per hour. The experiment uses as its basis a flow rate of 60 aircraft per hour.

Aircraft landing RDU will receive beacon code assignments from Washington Center, and use the same code for the duration of the flight. Weather conditions for this evaluation will be 1000 foot ceiling and 3 miles visibility, with RDU terrain visualization at twilight/dusk skies, and runway and surface lighting.

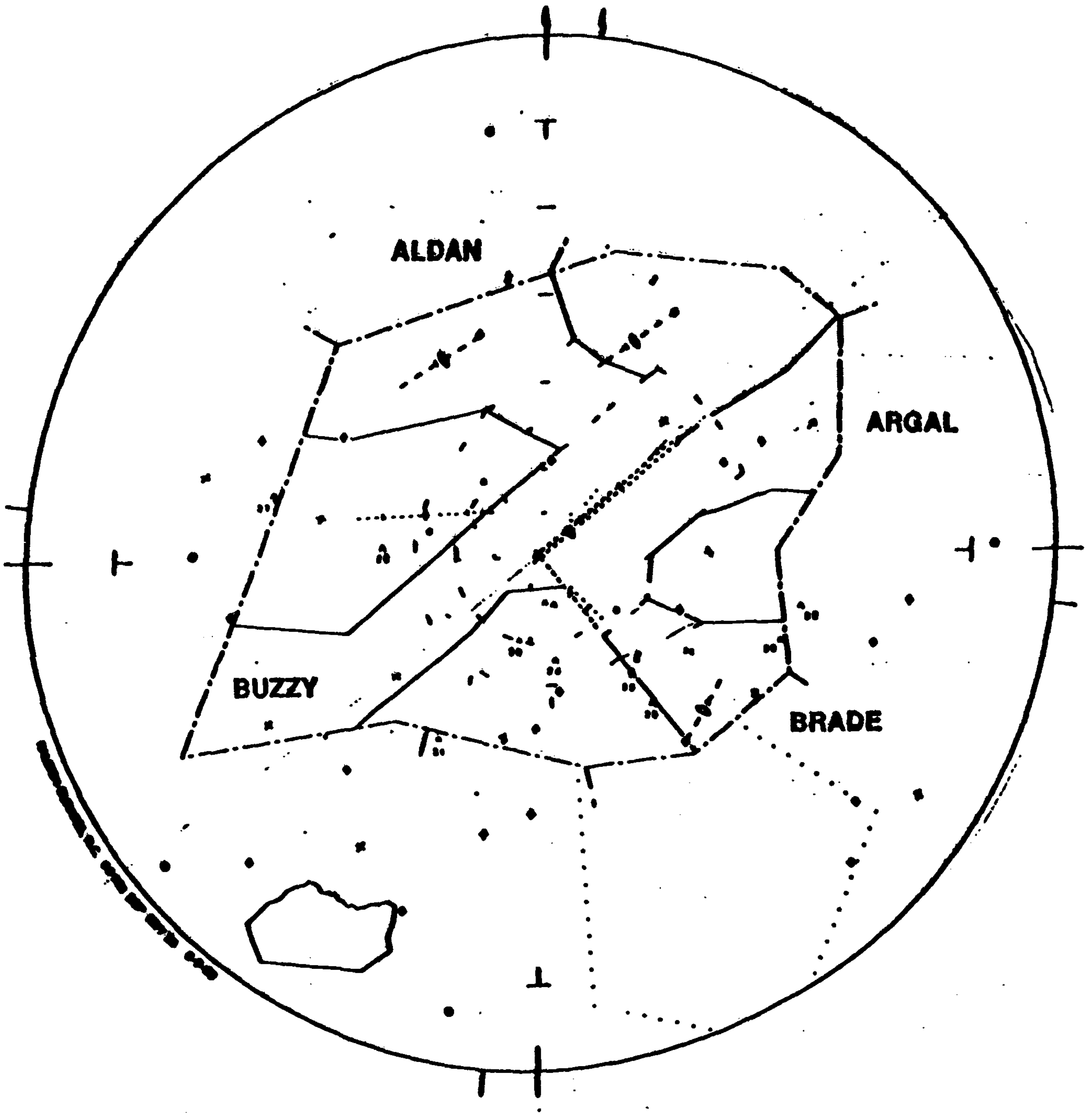

FIGURE C-1. RALEIGH-DURHAM AIRSPACE.

APPENDIX D

MISSION DESCRIPTION

1. MISSION DESCRIPTION.

1.1 INITIAL POSITION.

Aircraft simulators will begin near the cornerposts for the east or west arrivals, fixed in space, set up for initial approach conditions, eg., heading, speed, altitude. Aircraft state such as engine thrust will need adjustment so that the aircraft enters the scenario smoothly. The point locating aircraft position at scenario startup is referred to as the initial point (IP).

The IPs for ARGAL and BRADE are approximately 17 miles east and 8 miles north and 22 miles east and 12 miles south of the cornerposts respectively. IPs for ALDAN and BUZZY are approximately 5 miles west and 18 miles north and 10 miles south and 8 miles west of these cornerposts respectively.

Initial altitudes are 11,000 feet mean sea level (MSL) for ARGAL, BUZZY, and BRADE, and 10,000 feet for ALDAN. Initial speeds are 290 kts for all aircraft. Initial headings are 243 degrees (ARGAL), 300 degrees (BRADE), 171 degrees (ALDAN), and 60 degrees (BUZZY). Table D-1 lists the IP reference data.

TABLE D-1. INITIAL POSITION REFERENCE DATA.

Arrival Fix	Initial* Position		Crossing Altitude	Flight Segment
	Bearing in Degrees	Distance in Nautical Miles		
ARGAL	068	52	11,000 MSL	Arrival
BUZZY	234	52	11,000 MSL	Arrival
BRADE	125	52	11,000 MSL	Arrival
ALDAN	341	52	10,000 MSL	Arrival

*Bearing and distance to airport.

1.2 MISSION PROFILE.

Flight crews placed into the scenario at arrival IP will be expected to hand-fly standard approach transitions. Vectors from air traffic control will maneuver the aircraft through over- and under-flight traffic to an intercept with the Instrument Landing System (ILS) for a procedural landing. Crews are expected to execute a landing to a full stop. No departures will be flown.

During the data collection runs, some flights will be voice only, and some will be Data Link with voice. It is expected that three flights per run will be executed. Simulators will fly from either ARGAL and ALDEN or BRADE and BUZZY, alternating IP between flights.

1.3 SCHEDULE OF FLIGHTS.

Table D-2 lists the start times, IPs, corner posts, aircraft identifiers, and beacon codes for each scenario. Simulator sites should refer to this table when setting up to participate in the experiment.

TABLE D-2. SCENARIO REFERENCE DATA

SCENARIO A

TGT. NO.	START TIME	INITIAL POINT	CORNER POST	ACID	BEACON CODE	SIMULATOR
16	12:00:45	234/52	BUZZY	AAL140	2140	AVIA
42	12:32:15	125/52	BRADE	AAL240	2240	AVIA
68	13:04:45	234/52	BUZZY	AAL340	2340	AVIA
14	12:00:39	125/52	BRADE	DAL130	2130	DELTA
43	12:33:30	234/52	BUZZY	DAL230	2230	DELTA
69	13:06:00	125/52	BRADE	DAL330	2330	DELTA
13	12:00:36	068/52	ARGAL	TWA110	2110	NASA
33	12:21:00	341/52	ALDAN	TWA210	2210	NASA
54	12:47:15	068/52	ARGAL	TWA310	2310	NASA
70	13:07:15	341/52	ALDAN	TWA410	2410	NASA
15	12:00:42	341/52	ALDAN	USA120	2120	OK CITY
37	12:26:00	068/52	ARGAL	USA220	2220	OK CITY
53	12:46:00	341/52	ALDAN	USA320	2320	OK CITY
71	13:08:30	068/52	ARGAL	USA420	2420	OK CITY

TABLE D-2. SCENARIO REFERENCE DATA (continued)

SCENARIO B

TGT. NO.	START TIME	INITIAL POINT	CORNER POST	ACID	BEACON CODE	SIMULATOR
16	12:00:45	234/52	BUZZY	AAL140	2140	AVIA
42	12:32:15	125/52	BRADE	AAL240	2240	AVIA
68	13:04:45	234/52	BUZZY	AAL340	2340	AVIA
14	12:00:39	125/52	BRADE	DAL130	2130	DELTA
43	12:33:30	234/52	BUZZY	DAL230	2230	DELTA
69	13:06:00	125/52	BRADE	DAL330	2330	DELTA
13	12:00:36	068/52	ARGAL	TWA110	2110	NASA
33	12:21:00	341/52	ALDAN	TWA210	2210	NASA
54	12:47:15	068/52	ARGAL	TWA310	2310	NASA
70	13:07:15	341/52	ALDAN	TWA410	2410	NASA
15	12:00:42	341/52	ALDAN	USA120	2120	OK CITY
37	12:26:00	068/52	ARGAL	USA220	2220	OK CITY
53	12:46:00	341/52	ALDAN	USA320	2320	OK CITY
71	13:08:30	068/52	ARGAL	USA420	2420	OK CITY

SCENARIO C

TGT. NO.	START TIME	INITIAL POINT	CORNER POST	ACID	BEACON CODE	SIMULATOR
16	12:00:45	234/52	BUZZY	AAL140	2140	AVIA
42	12:32:15	125/52	BRADE	AAL240	2240	AVIA
68	13:04:45	234/52	BUZZY	AAL340	2340	AVIA
14	12:00:39	125/52	BRADE	DAL130	2130	DELTA
43	12:33:30	234/52	BUZZY	DAL230	2230	DELTA
69	13:06:00	125/52	BRADE	DAL330	2330	DELTA
13	12:00:36	068/52	ARGAL	TWA110	2110	NASA
33	12:21:00	341/52	ALDAN	TWA210	2210	NASA
54	12:47:15	068/52	ARGAL	TWA310	2310	NASA
70	13:07:15	341/52	ALDAN	TWA410	2410	NASA
15	12:00:42	341/52	ALDAN	USA120	2120	OK CITY
37	12:26:00	068/52	ARGAL	USA220	2220	OK CITY
53	12:46:00	341/52	ALDAN	USA320	2320	OK CITY
71	13:08:30	068/52	ARGAL	USA420	2420	OK CITY

APPENDIX E

ARTS LABORATORY PLAN

ARTS LABORATORY.

The ARTS IIIA laboratory is located in the FAA Technical Center and is composed of 11 controller workstations (figure E-1) and associated data processing equipment. For this study, eight of the displays were used by controllers or pseudopilots and one unit was moved outside the laboratory room and equipped with a video recording system. Unit 11 was used as a "ghost sector" where simulators and computer generated aircraft appeared before they were handed off to arrival controllers. Three Data Link workstations were added to the existing equipment. They served to display Data Link messages sent by controllers to pseudopilots.

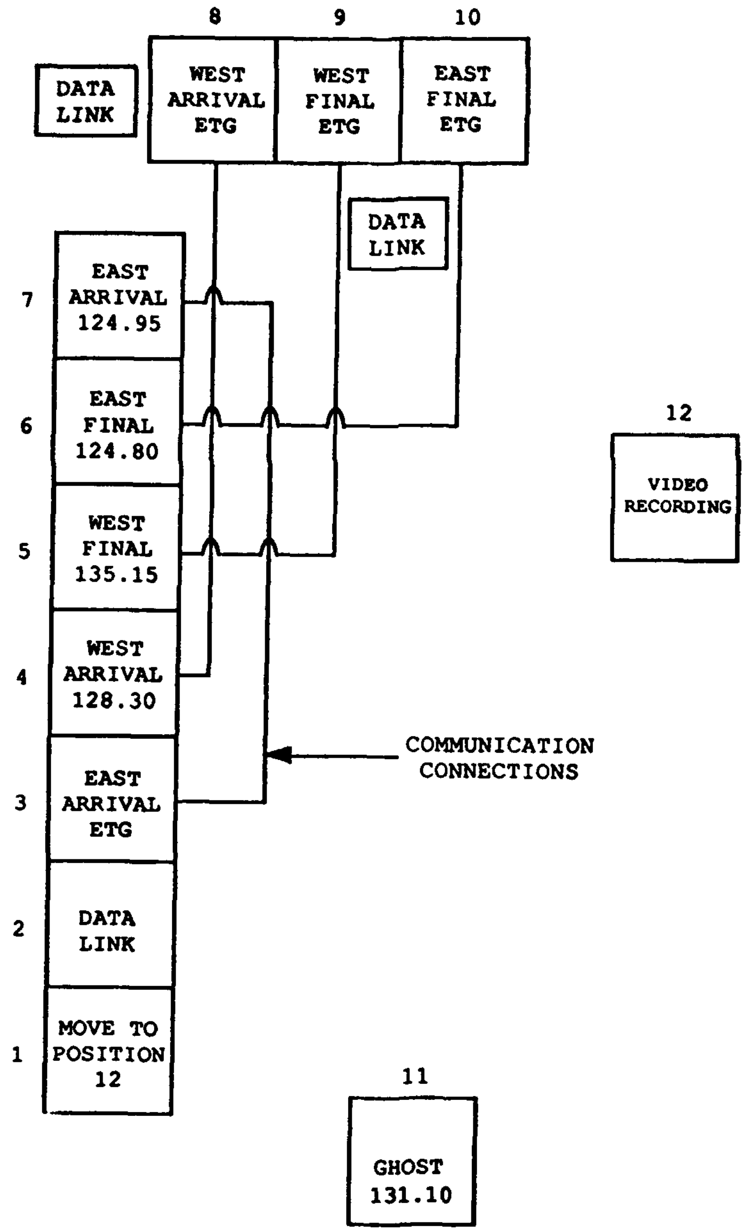

FIGURE E-1. ARTS LABORATORY PLAN. ("ETG" = Pseudopilot)

APPENDIX F

PERSONNEL ASSIGNMENTS

Personnel Assignments

Test Director	Richard Mogford
Facilities Coordinator	Jerry Guttman
Chief Site Coordinator	Andy Neustadter
Simulator Site Coordinators	
NASA Ames	Bob Geary Kim Mortenson
Oklahoma City	Tom McGill
Delta Airlines	John Dechara
AVIA Research	John Zinc Lou Conover
Simulator Site Technical Support	
NASA Ames	Jerry Jones Ian MacLure
Oklahoma City	Jim Nebgin
Delta Airlines	Sean Sandlin
AVIA Research	Dave Avery
ARTS Data Link Operators	Rickie Jones Sherry Courington Paula Amaldi
ARTS ETG Simulator Pilots	Smokey Mosely Nat Thomas Jeff Cramer Dick Kearns Fred Fontana Frank Fontana
ARTS Air Traffic Controllers	Charlotte Long Dave Lister Joe D'Alessio Jerome Karrels John Drug Evan Darby Rick Ozmore
ARTS Video Operator	Sherri Morrow
ARTS Ghost Position Controller	Jim Merel

VAX Operations	George Chandler Cuong Le
ARTS Operations	Joe Lunder Mike Headley
ARTS Computer Maintenance	Bill Cole

APPENDIX G

SCHEDULES

DAILY TEST SCHEDULE

Eastern Standard Time

1230	- 1400	Pilot Orientation
1400	- 1530	Run 1
1530	- 1545	Debrief
1545	- 1645	Meal Break
1645	- 1815	Run 2
1815	- 1830	Debrief and Break
1830	- 2000	Run 3
2000	- 2030	Debrief

Central Time

1130	- 1300	Pilot Orientation
1300	- 1430	Run 1
1430	- 1445	Debrief
1445	- 1545	Meal Break
1545	- 1715	Run 2
1715	- 1730	Debrief and Break
1730	- 1900	Run 3
1900	- 1930	Debrief

Pacific Standard Time

0930	- 1100	Pilot Orientation
1100	- 1230	Run 1
1230	- 1245	Debrief
1245	- 1345	Meal Break
1345	- 1515	Run 2
1515	- 1530	Debrief and Break
1530	- 1700	Run 3
1700	- 1730	Debrief

MARCH

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1	2	3	4	5	6
7	8 INTERFACE TESTING	9	10	11	12	13
14	15 INSTALL DL HARDWARE IN FIELD INTERFACE TESTING	16	17	18 DEBUG SCENARIOS	19	20
21	22 INSTALL DL HARDWARE IN FIELD DEBUG SCENARIOS (4 hrs., 2 days)	23	24	25	26	27
28	29 DEBUG WITH SIMULATORS (4 hrs., 1 day)	30	31			

APRIL

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1 DEBUG WITH SIMULATORS (4 hrs., 1 day)	2	3
4	5 DEBUG WITH SIMULATORS (4 hrs., 2 days)	6	7	8	9	10
11	12 DEBUG WITH SIMULATORS (4 hrs., 1 day)	13	14	15 TEST 1230-2030	16	17
18	19 TEST 1230-2030	20	21	22	23	24
25	26 TEST 1230-2030	27	28	29	30	

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